MORPHOLOGICAL DEFORMITIES IN LARVAE OF *Procladius* SKUSE (Diptera: Chironomidae): INDEXING DEFORMITIES IN LIGULAE AND ANTENNAE AND THEIR APPLICATION TO CONTAMINANT-STRESSED ENVIRONMENTS

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ABSTRACT

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A scheme for indexing the severity of deformities in the ligula of Procladius is presented and the scheme from Warwick (1985) for indexing deformities in the antennae revised. Both indices are expanded from population to community indices and are combined into a general index of Community Response (CR). These biological indices are compared with Indices of Contamination derived from published and unpublished chemical data from the St. Lawrence River, Port Hope Harbour, Southern Indian Lake-Notigi Reservoir, Tobin Lake and Last Mountain Lake. Despite obvious limitations in both data sets, the biological and chemical indices identified Lac St-Louis Site 4 on the St. Lawrence River as the most highly contaminated site and the Wupaw Bay site in the Southern Indian Lake-Notigi Reservoir the least contaminated of the 23 sites studied. Seasonal data from Rat Lake (SIL-NR) show that exposure to mercury at least increases in the summer months when water temperatures are warmer. Unlike chemical data, biological data do not suffer from a lack of "pieces" of information, but rather from our ability to read and interpret those "pieces" that are already provided. Interactions between a number of other physical, chemical and biological parameters are also discussed.

INTRODUCTION

Biological approaches to the assessment of water quality and the health of freshwater ecosystems offer a number of advantages over chemical and/or bioassay approaches alone. The biological approach represents a systems approach which focuses on the resource and its response to different environmental impacts. In contrast, the chemical/bioassay approach represents a regulatory approach which focuses on specific pollutants with specific rules for their discharge into the environment (Ohio EPA 1988). Biological communities are precise indicators of aquatic conditions because they are intimately bound to their environment and are directly subjected to the sum total of all chemical, physical and biological processes influencing that environment over the length of their life cycles. On the other hand, chemical measurements, and to a lesser degree bioassay measurements, are biased toward short term conditions that exist only at the time of sample collection (Warwick 1989a). Resident biological communities reflect both past and present conditions, usual or extreme, and include important variables that are not, or can not be, quantified or considered in chemical/bioassay analyses. The biological approach represents a "top down" evaluation where the end product, the community, is used to characterize the summed result of all chemical, physical and biological processes that affect biological performance. The chemical/bioassay approach, on the other hand, represents a "bottom up" evaluation where only a few variables are used in an attempt to simulate, predict or explain an assumed end result (Ohio EPA 1988).

Warwick (1985) proposed using morphological deformities in chironomid larvae as a measure of the long-term, chronic toxicity of contaminants in freshwater ecosystems. The family Chironomidae possess a number of advantages which make them particularly good indicators of aquatic conditions (Warwick 1989a). Among these are the size of the family, their widespread distribution, relatively short life span and sedentary behaviour, and their direct exposure to contaminants at the mud/water interface.

Warwick (1985) began a systematic evaluation of these responses to industrial and/or agricultural contaminants with development of an index for assessing the severity of deformities in the antennae of Chironomus Meigen. This was followed by publication of frameworks to categorize deformities in the other head capsule structures of Chironomus (Warwick and Tisdale 1988) and the head capsule structures (including the ligula) of Procladius (Warwick 1989b).

The present paper is an extension of Warwick (1989b); its primary objectives include 1) presenting an indexing scheme for evaluating deformities in the ligulae of Procladius, 2) comparing its efficacy on a number of sites experiencing differing degrees of contaminant stress, 3) applying the techniques of ISAD (Index of Severity of Antennal Deformation) in the assessment of the severity of deformities in antennae of Procladius, 4) evaluating the use of ISAD in genera other than Chironomus and 5) examining the inter-relationship between responses in the predator Procladius and the detritivore Chironomus. This is the second paper in a series the purpose of which is to develop indices for documenting and comparing deformities in chironomid larvae.

MATERIALS AND METHODS

The larvae used in this study came from a number of sites in eastern and western Canada (Table 1). Most of these have been discussed in greater detail in Warwick (1989b,c), but data from two additional sites in Tobin Lake have been included here.

The St. Lawrence River

The St. Lawrence River material includes specimens from three sites within the confines of the St.Lawrence Seaway off Laprairie, Quebec, seven sites in Lac St-Louis and two man-made sites connected with canals. The Laprairie basin sites are confined by the seaway dike system and thus are poorly flushed. The three sites monitor an increasingly severe environmental gradient extending from Site 3 near the Champlain bridge at Montreal, through Site 7a to Site 13a located offshore from the sewage treatment facility at Laprairie, Quebec. Untreated sewage from this facility has very seriously polluted the basin at this latter site.

The Lac St-Louis sites include Site 2 located near the confluence of the St. Lawrence and Ottawa Rivers; Sites 3,4,5 and 6 located in a small bay immediately offshore from the Union Carbide industrial complex at Beauharnois, Quebec; Site 7 located eastward off the mouth of the St-Louis River; and Site 8 located even further eastward in a bay protected from the main flow of the St. Lawrence River by the island and reef complex around Isle aux Plaines.

The man-made sites include Site 1 located in the ship-mooring basin above the St-Catherine locks and Site 9 located at the upper end of the Lachine

canal. Site 1 is dredged, comparatively deep and exposed to contaminants from ships in transit through the canal. Site 9 is located in the protected basin at the entrance to the Lachine Canal which serves as an anchorage for the Iroquois Yacht Club.

Southern Indian Lake-Notigi Reservoir

The Southern Indian Lake-Notigi Reservoir material includes larvae from four sites exposed to the effects of increasing water level change and erosion as new beachlines were established following filling of the reservoir. Prior to flooding, the Wupaw Bay basin was stressed by wind action because of its shallow depth. Although increased water levels (3.1 m) have caused some minor erosion, these largely have improved the bottom environment of silty-clay by the deeper water decreasing exposure to wind stress. In contrast, similar water level increases (3.1 m) have severely impacted the South Bay basin which is exposed to a broad fetch of wind. Bank erosion has been severe here with much organic debris from the forest floor adding to the mineral soils eroding into the bay. The classification of South Bay sediments as clayey-silts is misleading in that mineral sediments have eroded into the bay as "clay balls" ranging in size from 2 cm diameter to sand and silt sizes (Hecky and McCullough 1984) which bias the particle-size distribution towards the coarser size fractions.

Although exposed to greater changes in water depth (6.9 m), only minor bank erosion appears to have occurred in the Mynarski Lake basin. The sediments at this site are highly organic and finely divided to the extent that they are classified as clay-sized sediments. In the Rat Lake basin there is evidence of greater erosion stress. With an increase in depth of 15.2 m, the silty-clay

sediments characteristically have a tail of very fine sediments (15.98%) which suggest either erosion and deposition of newly flooded soils or mineral sediments borne in by the Suwannee River (Warwick unpubl. data). The degree to which attendant fauna have been exposed to increased mercury levels has been correlated with the extent of areal flooding in the different basins of the reservoir (Bodaly et al. 1984a,b).

Last Mountain Lake

The Last Mountain Lake material includes specimens from sites off Saskatchewan Beach (Site I) and Rowan's Ravine (Site II) on the east-west and north-south arms of the lake, respectively. Site I is contaminated by water from the Qu'Appelle River which is shunted back up into the lake in the spring to alleviate downstream flooding in the Qu'Appelle valley. Contaminants from this source probably are confined to the lower reaches of the lake and do not impact Site II to any degree. Both sites probably receive some agricultural contaminants from the surrounding farming areas (Warwick 1985).

Tobin Lake

The Tobin Lake material includes specimens from four sites. As described previously, Site 2 is located just below the inflow of the Saskatchewan River into the reservoir and is directly exposed to the impact of the full contaminant and sediment burden of the river. Site 17 is located in a flooded backwater area and probably only receives contaminants indirectly. Mineral sediment accumulation from flooded agricultural areas flanking the old Petaigan River valley may be considerable because their shallow waters are heavily wind-stressed and subject to draw-down exposure (Warwick and Tisdale 1988). The two Tobin Lake sites added in this report are Sites V and VI from Warwick

(1985). These sites lie in the old submerged Saskatchewan River channel towards the lower end of the reservoir. The sediments of both sites are highly organic, but the sediments at Site VI were particularly noteworthy for the large quantities of wood-pulp fibriles, possibly from the pulp and paper mill at Prince Albert, Saskatchewan.

Port Hope Harbour

The Port Hope Harbour material includes specimens from three sites located in the inner harbour (Cook and Veal 1968; Sites B, C and E)). The basin is heavily contaminated by radionuclide wastes, cooling water and trace metals from the nearby Eldorado Nuclear Limited uranium refinery, the Port Hope Yacht Club and the adjoining townsite.

The details of collection, preparation and mounting of larval specimens is given in Warwick (1985, 1988) and Warwick and Tisdale (1988).

An Index of Contamination (I c) was calculated for each site according to Champoux and Sloterdijk (1988) as:

$$I_c = \frac{\sum_{i=1}^{k} \frac{(teneur)_i}{(critere)_i}}{k}$$

where 'teneur' is the concentration of contaminant in the surficial sediment, 'critere' is the not-to-exceed concentration for that contaminant established by the Ministry of the Environment for Ontario (MOE) and 'k' is the number of variables used. A value less than one signifies that , on the average, the concentration of contaminants is less than the MOE criteria whereas a value greater than one indicates contamination exceeding the MOE criteria.

STRUCTURE OF NORMAL LIGULAE

The normal ligula of Procladius (Fig. 1a) has five dark brown to black teeth which are apically concave and flexibly-mounted on the prementohypopharyngeal complex. The ligula is tubular in structure and usually wears or breaks unevenly. It is flanked on either side of the base by leaf-shaped paraligulae. The ligula is analogous to the mentum in other chironomid subfamilies.

INDEXING THE SEVERITY OF LIGULA DEFORMATION

Classification of Deformed Ligulae

Warwick (1989b) established a framework of eight basic categories of deformity in the ligula. These were:

1) the number of teeth;
2) modifications to the larger, outer teeth;
3) overlapping of teeth;
4) the presence of accessory teeth;
5) the presence of forked teeth;
6) fusing of the ligula and paraligula;
7) massive disorganization; and
8) asymmetry

These categories form the basis for the steps followed in assessing a cumulative ranking for the severity of ligula deformation according to the following guidelines:

Step 1. The Number of Teeth

The category "number of teeth" is based on those teeth in a deformed ligula included in the classical apically-concave pattern. Within this pattern, deformed ligula may have numbers of teeth less than (Fig. 1c), greater than (Figs. 1d,e) or equal to (Fig. 1b) the normal complement of five teeth. The ranking for each deviation from the normal pattern begins with a value of one for a ligula with five teeth, one of which is abnormal (Fig. 1b), and doubles thereafter for each tooth lost or added to the ligula. Thus, ligula with four (Fig. 1c) or six (Fig. 1d) teeth are assigned a value of two while those with two extra, or seven teeth (Fig. 1e), are assigned a value of four. In the extreme case where no recognizable teeth are present (Fig. 2p), the value assigned under the category "number of teeth" would be 32. At the other end of the scale, that is, in those ligula with additional teeth, the upper limit is not constrained.

Step 2. Modification to the Larger, Outer Teeth

This category involves the reduction in size of the larger, outer teeth of the ligula. Since such a reduction places these teeth outside the classical apically-concave pattern, it is treated in separate. Thus, in Fig. 1f, the number of teeth is four and one outer tooth is modified in size and length. The value assigned a modified outer tooth is two.

Step 3. Overlapping of Teeth

The category "overlapping of teeth" is based simply on the number of overlapping teeth, for each of which is assigned a value of four. Thus, the single overlap between the two outer teeth of the ligula in Fig. 1g would be assigned a value of four.

Step 4. The Presence of Accessory Teeth

Accessory teeth are small teeth mounted high on the inner waisted curve of the ligula (Fig. 1h). These teeth sometimes can be difficult to differentiate from extreme examples of modified outer teeth or fusing between the ligula and paraligula. Colouration usually provides the key for distinguishing between these types. The colouration of accessory teeth is continous with that of the main teeth. Each accessory tooth is assigned a value of eight. The ligula in Fig. 1h which has two accessory teeth is therefore assigned a total of 2x8 or 16 points.

Step 5. The Presence of Forked Teeth

Forking can occur in any one (Figs. 1i-l) or more (Fig. 2l) of the teeth on the ligula. Each occurrence is assigned a value of 16. Forked teeth can occur singly (Fig. 1i,j) or in combination (Figs. 1k,l) with other types of deformities to the extreme example in Fig. 2l where three forked teeth account for 48 of the total of 68 points assessed the deformed ligula.

Step 6. Fusing between the Ligula and Paraligula.

Fusing between the ligula and paraligula can take several forms ranging from pedestal-mounted paraligula (Figs. 2a,d), to toothed paraligula replacing (Fig. 2b), or in addition to (Fig. 2c), the normal complement of paraligula and simple or untoothed paraligula fused directly to the side of the ligula (Fig. 2i). The latter example (Fig. 2i) illustrates a case where differentiation between accessory teeth and fused paraligula can become problematic. In this case, there is a distinct colour separation between the paraligula and the main body of the ligula which makes differentiation possible. The ligula in Fig. 2h is an excellent example of the two types of deformity occurring side by side.

Presently, each instance of fusing is assigned a value of 32. As more information becomes available, it may be possible to further refine the distinction between these types of fusing.

Step 7. Massive Disorganization

Massively deformed ligulae are difficult to describe verbally and are best illustrated as in Fig. 2. The massively deformed ligula presented here were all found in sites where heavy contamination might be anticipated; two (Figs. 2m,p) came from sites immediately offshore from the Union Carbide industrial complex at Beauharnois, Quebec, and two (Figs. 2n,o) from Tobin Lake Site 2 where exposure to the contaminant burden of the Saskatchewan River is most direct. Massively deformed ligulae are assigned a base value of 64.

Step 8. Asymmetry

Ligula displaying extensive asymmetry are also shown in Fig. 2. Those in Figs. 2j,k both occurred in very early instar larvae. This suggests that this type of deformity may result from interference in the transition process between early instar stages. This type of deformity is similarly assigned a base value of 64.

Calculation of the Index of Morphological Response

An Index of Morphological Response (IMR) is calculated for each deformed ligula according to the seven basic steps discussed above and summarized in Table 2. IMR represents the cumulative total of the values assessed each category of deformity, singly or in combination, as shown in the following examples of two severely deformed ligula. The ligula in Fig. 2o has four teeth (2), one of which is overlapped (4), one fused paraligula (32) and is massively

deformed (64) for an IMR value of 102. The second example in Fig 2p has no teeth (32), both paraligula are fused (64) and is massively deformed (64) for an IMR value of 160. These calculations and those for the other deformed ligulae shown in Figs. 1 and 2 are presented in detail in Table 3.

Calculation of the Index of Severity of Ligula Deformation (ISLD) at Population and Community Levels

The ISLD is interpreted as a measure of the morphological response to stress exhibited by the ligulae in a Procladius population exposed to toxicants in the aquatic environment. The index is defined simply as:

$$ISLD = \frac{\Sigma IMR}{'n'}$$

where Sum IMR is the sum of individual IMR values for each Procladius population divided by 'n' the number of Procladius larvae in that population. This represents a more precise definition of ISxD than that given previously in Warwick (1985) which also is a population-based calculation.

To broaden the calculation to include other members of the chironomid community, a new calculation is proposed based on the total chironomid community. The new index is defined as:

$$ISLD_{TOTAL} = \frac{\Sigma IMR}{'N'}$$

where Sum IMR is now divided by 'N' the total number of chironomid larvae examined.

STRUCTURE OF NORMAL ANTENNAE

The antenna of normal Procladius has been described in detail in Warwick and Tisdale (1988) and Warwick (1989b). In brief, it has four segments (Fig. 3a), the basal segment of which is considerably longer than the total length of the three remaining segments. The basal segment is equipped with a ring organ distally, but apparently no basiconic sensillum. The blade/accessory blade complex is located on the articulating membrane between the first (basal) and second antennal segments (enlargement Fig. 3b). Two tiny reniform structures also located on this membrane have tentatively been identified as peg sensilla. These probably serve the same function as those in Chironomus (Warwick and Tisdale 1988). Three structures are located at the apex of the second segment, the larger of which is a heavy walled structure similar to the style in Chironomus. It probably serves as a mechanoreceptor as well. The two smaller tubular sructures, (referred to as sensory pegs SP 1 and SP 2 in Roback 1980) are mounted on individual pedestals rather than directly on the articulating membrane. As Warwick and Tisdale (1988) suggests, their location seems to rule out a mechanoreceptor role whereas their structure is more in keeping with that of thick-walled chemoreceptors involved in direct contact reception of stronger chemical stimuli (Slifer 1970).

INDEXING THE SEVERITY OF ANTENNAL DEFORMATION

Classification of Deformed Antennae

Warwick (1989b) established a framework of six basic categories for

indexing antennal deformities following Warwick (1985). These were:

1) basic classification categories
   (a) loss of genuine segments
   (b) presence of questionable segments
2) reduction in antennal length
3) displacement, loss or addition of ring organs
4) apical fusing of basal segments
5) displacment, loss or addition of sensory organs
6) structures of unknown homology
   (a) major structures
   (b) minor structures

Step 3 was modified from Warwick (1985) to include the addition of extra ring organs as shown in Fig. 3d. As was the case for the loss of a ring organ, each additional ring organ is assessed a value of two. Step 5 was similarly modified to include the loss or addition of sensory organs as in Figs. 3g,h. Each occurrence is assigned a base value of two.

Calculation of the Index of Morphological Response

An Index of Morphological Response (IMR) is calculated for each deformed antenna or pair of deformed antennae according to the six basic steps discussed above and summarized in Table 4. IMR represents the cumulative total of the values assessed each category of deformity, singly or in combination, as shown in the examples in Fig. 3. The antennae in Fig. 3g,h differ from normalcy only by the addition of one extra accessory blade. Each adds two points to the basic assessment of IMR. In Procladius, because the larvae only have four antennal

segments originally, the basic assessment is five rather than one as for Chironomus. This adherence to Warwick (1985) introduces a bias to the calculation, but this has been accepted in part as a counter to the seeming lack of sensitivity in Procladius antennae (Warwick 1989b). This ruling is provisional and may have to be modified as more data becomes available.

The additional ring organs on the antenna in Fig. 3d add seven points to the total IMR value. Two points are assessed for each additional ring organ and three points are assessed because all are displaced apically on Segment I. The antennae in Figs. 3e,f, in addition to the number of segments lacking, have present a number of structures of unknown homology. The calculations for these examples are detailed in Table 5.

Calculation of the Index of Severity of Antennae Deformation (ISAD) at Population and Community Levels

ISAD is interpreted as a measure of the morphological response to stress exhibited by antennae in Procladius populations exposed to toxicants. The index is defined as:

$$ISAD = \frac{\Sigma IMR}{n}$$

where Sum IMR is the sum of individual IMR values for each Procladius population divided by 'n' the number of Procladius larvae in that population. This represents a more precise definition of ISAD than that given previously in Warwick (1985). Although implied, the definition of 'n' in this earlier work should have been more clearly given as "the number of Chironomus specimens examined."

As for ISLD, the calculation of ISAD has been broadened to include other members of the chironomid community in a new index defined as:

$$ISAD_{TOTAL} = \frac{\Sigma IMR}{'N'}$$

where Sum IMR is now divided by 'N' the total number of chironomid larvae examined. Values cumulated under these indices eventually will be used to provide a measure of population morphological response (PMR) such as:

$$PMR = \sum_{PROCLADIUS} (ISLD + ISAD + \cdots + ISxD)$$

or a more comprehensive measure of chironomid community response (CCR) such that:

$$CCR = \sum_{PROCLADIUS} (ISLD_{TOTAL} + ISAD_{TOTAL} + \cdots + ISxD_{TOTAL}) + \sum_{OTHER} (ISxD_{TOTAL})$$

DEFORMITIES IN STRESSED AND UNSTRESSED POPULATIONS OF Procladius

Occurrences in Ligulae

Data on the occurrence of deformed ligulae in contemporary communities is difficult to obtain because there are few contemporary environments left untouched by contaminants of one form or another. Such data are available from the subfossil record, however.

The best estimate of background frequencies of deformed ligulae comes from the Bay of Quinte, Lake Ontario (Warwick 1980). During the pre-European period,

the frequency of deformed ligulae ranged from zero to 0.09% (Table 6). The two deformed ligulae found both featured modifications to one of the larger, outer teeth and both appeared during periods of stress caused by increasing accumulations of mineral sediments. Following European settlement in 1784, however, the frequency of deformities increased by an order of magnitude in the more modern subfossil and contemporary communities. This holds true whether determined on a population or community basis. The closer correlation between the biocoenosis and the thanatocoenoses of the upper level sediments suggests that that based on the community may be the more reliable predictor.

If the value of 0.09 is used as an upper level for the background frequency of ligula deformities, the values of ISLD for the St. Lawrence River sites exceeded background frequencies from 2X to 20X (Table 7). In Lac St-Louis, the highest value came from Site 4, immediately offshore from the industrial complex at Beauharnois, Quebec, and the lowest from Site 8, the area protected from the main flow of the St. Lawrence River by the island chain around Isle aux Plaines. Of the two man-made sites, the value of ISLD was higher at Site 9, the upper end of the Lachine Canal, than at Site 1 at the St-Catherine locks. ISLD values for these sites exceeded background levels by 12X and 8X, respectively. In the Laprairie basin, the highest value of ISLD came from Site 3, the site least severely impacted by domestic wastes from the Laprairie treatment facility. From this, it would appear that responses to chemical contamination either follow secondarily to the severe conditions imposed by gross pollution or high loadings of organic waste reduce exposure to contaminants through the effect of dilution.

The values of ISLD for Last Mountain Lake (Table 8) reflect the differences

in exposure to contaminants at the two sites. At Site II, the value of ISLD was zero whereas that at Site I was 0.106. The former site is comparatively uncontaminated whereas the latter is contaminated by spring flood water shunted back up into the lake from the Qu'Appelle River. The sensitivity of the index is suggested by adherence to the pattern of contamination expected in Last Mountain Lake. This also suggests that the two measures of response from the pre-European period in the Bay of Quinte were indeed measures of (sedimentation) stress and that, instead of a value of 0.09, background levels for ISLD might more appropriately be set at zero.

The value of ISLD for Rat Lake (summer) is very low, but it also is based on a very small number of Procladius larvae. To get a better estimate of ISLD would entail a tremendous amount of work because of the imbalance between the Chironomus and Procladius components of the community. However small the data base, the data do show an increase from zero in the spring population to 0.026 in the summer population.

The values of ISLD for the Mynarski Lake basin and Tobin Lake Site 17 are very comparable to that for Last Mountain Lake Site I and suggest a comparable levels of contamination (Table 8). The value for Tobin Lake Site 2 is clearly higher than Site 17, but not to the extent one might expect from the greater loading of contaminants. It may be that the higher rates of sedimentation at this site also restrict exposure to contaminants through the effects of burial.

The value of ISLD for Port Hope Harbour (Table 8) exceeded pre-European settlement values by almost 25X. Taken at face value, it would seem from this that this site is the most heavily contaminated site described herein.

Occurrences in Antennae

The closest approximation to background levels of deformed antennae in Procladius probably comes from comparatively uncontaminated Last Mountain Lake Site II (Table 9). The value of ISAD for Site I, the more contaminated site, is 1.5X higher and follows the same pattern as ISLD. The value for the Mynarski Lake basin is equivalent to that of Last Mountain Lake Site I while that for Tobin Lake Site 2 is 4.5X higher.

The lowest value for the St. Lawrence sites was from Site 7. It was roughly equivalent to that for Tobin Lake Site 2 as were the values for ISLD. It is interesting to note that both are lake sites influenced by sediments from inflowing rivers. The highest value of ISAD came from Site 4 immediately offshore from the Union Carbide industrial complex at Beauharnois, Quebec.

ESTIMATES OF CONTAMINANT STRESS

Intra-basin Comparisons

Trace metal data from Serodes (1978) indicate a trend of increasing contamination toward the Laprairie sewage treatment facility (Table 10). The Index of Contamination (I$_c$) increased from 1.37 at Site 3 to 3.42 at Site 13. Of the six metals measured, zinc and chromium concentrations were particularly high. These metal data, although dated, come from sites that are directly comparable to the sites sampled in this study.

Trace metal data from Champoux and Sloterdijk (1988) are more current with respect to date, but the siting is less directly comparable (Table 10). Sites L-2 and L-6 are comparable to Sites 7 and 8 in this study. Site L-21 is located

in the bay offshore from the Union Carbide industrial complex at Beauharnois and relates generally to Sites 3-6 while Site L-12 is located near enough to Site 2 that it can give a good idea of the of contamination prevailing there. According to these data, the sites located offshore from the Union Carbide industrial complex have a much higher level of contamination (I_C = 5.22) than the other sites in the area.

This difference is made even more apparent when organic contaminants are added into the calculation (Table 11). The Index of Contamination at Site L-21 was an order of magnitude higher than any of the other sites. With a value of 20.33, the area immediately offshore from the industrial complex at Beauharnois is clearly a problem area. Also not unexpectedly, the lowest Index of Contamination came from Site 8 in the area protected by the reef and island complex around Isle aux Plaines.

Trace metal data for sites in Southern Indian Lake-Notigi Reservoir generally produced lower indices of contamination than their eastern counterparts (Table 12). These are based only on five trace metals, but there is sufficient information at least to make comparisons within the data set itself. In this context, the highest Index of Contamination came from the Mynarski Lake basin while the lowest came from the spring data set from Rat Lake. The higher Index of Contamination for the summer data set from Rat Lake suggests, as do the ISLD indices, that the effects of contaminants may vary seasonally.

The trace metal data for the two Tobin Lake sites (Table 12) pose an interesting problem; the Index of Contamination for Site 2, the more directly impacted site, is lower than that for Site 17 which is only indirectly affected

by contaminants from the Saskatchewan River. Although it may be possible that Site 17 is the more heavily contaminated, it is more likely that Site 2 either is affected by contaminants that were not measured (e.g. organic contaminants) and which would therefore not figure in the Index of Contamination, or possibly the high rates of sediment accumulation at this site limits exposure of resident communities to incoming contaminants. Because of burial, contaminants are not allowed to concentrate at the mud-water interface where most larval activity occurs.

The trace metal data for Port Hope Harbour gave a comparatively high index of contamination (Table 12) even without the inclusion of the radionuclide data (Table 13). Of the seven metals for which MOE criteria are available, lead and copper appear particularly troublesome in the inner basin of the harbour.

Inter-basin Comparisons

Comparisons between the five primary data sets are largely unsatisfactory. The only trace metals common to all sites were zinc and copper (Table 14). Indices based on these two metals, although they may give some idea of the relative states of contamination, would have to be used with the utmost caution.

To achieve greater commonality, different combinations of metals were used to compare different combinations of data sets (Table 14). The effect of the addition or deletion of different metals, particularly those making major contributions to the toxic burden, becomes apparent very quickly. For example, in Table 14, the Index of Contamination for Port Hope Harbour based on all seven metals measured was 3.32. When cadmium, cobalt and chromium are sequentially deleted for greater commonality with the Lac St-Louis and

Laprairie basin sites, leaving only zinc, copper, lead and nickel to form the basis of the index, it increases 4.73. If lead alone was used, the index would rise to 14.0.

The same effect is apparent in comparisons between the Tobin Lake and Lac St-Louis sites. While the deletion of cobalt and chromium to achieve commonality with all four Lac St-Louis sites apparently has little affect on overlapping Sites 7 and 8, the indices for the two Tobin Lake sites are themselves significantly reduced.

To rely solely on trace metals would also underestimate the contaminant burden. If organic contaminants were included, the Index of Contamination for the Lac St-Louis sites would increase, particularly at Site L-21. Similarly, the Index of Contamination for Port Hope Harbour would most likely be higher if the effect of radionuclides could be factored into the index. The high oxygen demands imposed by untreated domestic sewage would undoubtedly also have an effect on the overall contaminant burden at Laprairie basin Site 13a. From these few examples, it is easy to see that many factors, both abiotic and biotic, are involved in how contaminants react in the environment. To get an accurate estimate of contaminant burdens by chemical analysis is an involved and complicated process.

Comparison of Community Responses

The Community Responses (CR) to contaminants in Table 15 are based on the subset of Procladius ligulae and antennae. For communities like Lac St-Louis where Procladius is predominant, these indices probably are relatively accurate. Data for deformities in the paraligulae, hypopharyngeal pecten, dorsomenta and mandibles are not included here, but they form a relatively

minor component of the total response (Warwick 1989b). From their distribution, these deformities probably will enhance rather than degrade the present pattern, but this will have to be confirmed when suitable indices have been developed for these structures.

In communities where Procladius does not predominate, indices based on this subset are less accurate. This becomes apparent in the Laprairie basin sites where Chironomus are the dominant component of the community. Based solely on Procladius, the community response is inversely related to the contaminant gradient which increases from Site 3 to Site 13a. However, when even the ISAD values alone for Chironomus are factored into the community index, the response is reversed to coincide with the gradient anticipated from field observation. ISAD for Chironomus for Sites 3 and 7a were 0.032 and 1.647, respectively. When this subset is added to the subset for Procladius, community response for Sites 3 and 7a become 1.726 and 2.765, respectively. This result, although still based only on a partial analysis, gives a much clearer estimate of the actual conditions prevailing in this highly stressed environment. However, this does not seem to follow to its logical conclusion at Site 13a, the site closest the sewage outfall. Conditions there are so extreme that only a remnant fauna remains with too few animals to get a good biological 'fix' on this site.

In Last Mountain Lake, Community Responses, whether based solely on Procladius ligulae and antennae or including antennal data for Chironomus, reflect the greater degree of contamination at Site I than at Site II. When both taxa are included in the index, response was 0.147 and 0.114 at Sites I and II, respectively. The proportions of the two taxa differ considerably at the two sites, however. At Site I, Procladius predominates forming more than

50% of the chironomid community whereas at Site II, Chironomus predominates making up almost 90% of the total community. This becomes important if, as Warwick (1989) hypothesized, Chironomus is more sensitive to contaminant stress than Procladius. If, for sake of argument, the relationship is as follows:

$$CCR_{TOTAL} = CCR_{CHIRONOMUS} + K_1 CCR_{PROCLADIUS} + K_2 CCR_{OTHER}$$

where K_1 is arbitrarily set at 10, the Procladius portion of the index would increase by an order of magnitude to 1.18 and 0.08, respectively. Including Chironomus then, Community Response would increase to 1.209 and 0.186 for Sites I and II, respectively. The factor of 10X used here is hypothetical, of course, but it does convey the idea different tolerances may have on the calculation of the more comprehensive Index of Community Response.

Differences in tolerance may also factor in larval responses at Tobin Lake Sites 2 and 17. The proportions of Procladius and Chironomus are very similar at each site so the effect of community structure is cancelled out. Community Response based only on Procladius ligulae and antennae (Table 15) follows the trend anticipated for these sites, but when ISAD values for Chironomus of 0.261 and 0.663 for Sites 2 and 17, respectively, are added in (without taking into account the multiplicative factor for Procladius), the relationship is reversed. If the indices for Procladius are corrected for different sensitivities as suggested above (ie. $k_1 = 10$), however, Community Response for Sites 2 and 17 become 3.531 and 1.788, respectively, which again reflects the sequence one would expect for these sites.

Tobin Lake Sites V and VI are located further into the reservoir along the submerged main channel of the old Saskatchewan River (Warwick 1985). Conditions

probably are very severe here, particularly near Site VI where massively deformed larvae have been found. Procladius are rare or absent at these sites leaving only Chironomus for assessment. ISAD values for this genus were 1.632 and 1.193 for Sites V and VI, respectively. If the Community Responses for Sites 2 and 17 are corrected for different susceptibilities as above, the values Sites V and VI are lower than Sites 2 and 17 when in fact they should be higher if the theory on which the Tobin Lake study is based is correct. This points to two possible problems; either the hypothetical factor of 10X assigned Procladius is too high or ISAD in itself is not sufficient and indices for all structural parts need to be included to get a more accurate assessment of Community Response.

The Southern Indian Lake-Notigi Reservoir data are interesting in that only Mynarski Lake, the least impacted of the four sites, registered measureable Community Response based on Procladius ligulae and antennae. Comparable data for Chironomus unfortunately are not yet available for inclusion in the index. In South Bay, Procladius made up almost 50% of the fauna, and yet there was no visible response to elevated mercury levels in this environment. The bay is very exposed to wind stress and it may be that exposure to mercury is minimized by the large quantities of mineral sediments eroding and depositing from newly flooded shorelines. The Rat Lake data suggest that there may be differences in exposure between spring and summer fauna. Ramsey and Ramlal (1986) have shown that methylation of mercury by bacteria increases in the warmer waters of the summer months and the differences noted here may be due to this. If that is the case, chironomid communities may be more sensitive to contaminants (mercury at least) than was previously expected.

The Community Response based on Procladius ligulae and antennae for Port Hope Harbour (Table 15) was the highest recorded in this study. Procladius formed the greater proportion (74%) of the fauna while Chironomus formed the greater proportion (24%) of the remainder. It is important to note here that no deformed antennae were found in either fauna and that in Chironomus almost every larvae had at least one type of deformity in the other structures of the head. Antennae are thought to respond to contaminants according to quantal dose-response theory (Warwick 1988) where placement on the bell-shaped curve becomes important in interpretation. In the extreme environment of Port Hope Harbour, this clearly puts the remnant populations on the resistant (right-hand) side of the curve.

Community Responses and Indices of Contamination

Community Responses based on the Procladius ligulae and antennae subset (Table 15) clearly mark the area off the Union Carbide industrial complex at Beauharnois, Quebec, as a problem area. According to Champoux and Sloterdijk (1988), PCB concentrations are particularly high in this bay. The biological indices from the four sites within the bay similarly reflect the severity of contamination, but also indicate that the distribution of contaminants is concentrated more toward Site 4 located directly offshore from the industrial complex.

Both indices decline eastward away from the bay (Table 15). Although the indices of contamination progressively decline toward Site 8, there is a slight inversion in the biological indices between Sites 7 and 8. This may be due to the fact that these indices are based only on a partial subset of community response, but the fact that Site 7 lies off the mouth of the St-Louis River

suggests that mineral sediments transported in by river currents may reduce population exposure to contaminants by effectively burying much of the contaminant burden.

Both indices are high at Site 2 as well. Whether this response is to St. Lawrence River water from upstream sources or contaminants transported from the inner bay at Beauharnois is not known. Certainly the pattern of water currents interpreted from the area's morphometry make this latter a distinct possibility.

In the Southern Indian Lake-Notigi Reservoir, both indices correspond well (Table 15). Both were highest in the Mynarski Lake basin. This site is the least impacted of the four responding sites. Water level increases and their attendant redeposition of mineral sediments were minimal at this site. I suspect the greater response is due more to the greater availability of contaminants (ie mercury) in the highly organic sediments at this site than any real increase in concentration. The increase between spring and summer populations of Procladius in Rat Lake suggest a seasonal factor may be operative. This is further suggested by ISAD values for Chironomus which increase from 0.029 to 0.106 in spring and summer populations, respectively. The minima shown here in the Southern Indian Lake-Notigi Reservoir fauna also suggest that the lower limit of response in Procladius may lie between 0.78 and 0.94.

The Community Response for Port Hope Harbour (Table 15) is the highest recorded so far for Procladius. If Warwick's (1989b) hypothesis is correct, the fact that Chironomus still forms an important component of the community at this site suggests that it is not as badly impacted as those sites immediately

offshore from the Union Carbide industrial complex at Beauharnois where it has virtually been eliminated. It may be too that it is just as badly impacted, but the response is due to a different suite of contaminants. It is almost axiomatic that different contaminants will illicit different responses in different taxa and different environments.

DISCUSSION

The present data provide an opportunity to compare similarities and differences between a direct measure of biological response (deformities) and surrogate measures (chemical data) under a wide variety of conditions. The correspondence between the two measures is quite good despite the limitations in both types of data. The chemistry data have suffered not only from the fact that they were not dedicated to this purpose, but also from the fact that all the "pieces" were not, or could not, be measured. It would be extremely difficult and immensely costly to measure every contaminant in freshwater, even if these were known. For example, D. A. Birkholz (pers. comm.) estimated that there were some 5,000 chemicals of concern in the sediments of Tobin Lake. To unravel this mixture, its components, their byproducts and the products of synergistic/antagonistic interactions would be a formidable task.

The biological data at this point suffer not from the lack of "pieces," but from our inability to interpret the message each is trying to convey. Resident communities, of which the Chironomidae form an integral part, provide all the "pieces" to the biological "puzzle." What we require are the tools, the Rosetta

Stone if you will, to decipher the story these communities impart. These tools are gradually being developed and even at this stage the rewards have been very encouraging. The present paper adds a new genus to the list of responding taxa and methods for assessing the severity of deformities in its ligulae and antennae. Information regarding deformities in structures like the mandible, premandible, dorsomenta and hypopharyngeal pecten is currently being assembled to provide the remaining "pieces" to the Procladius "puzzle."

While these biologically-based techniques are not without drawbacks, Cairns (1988) notes that "there is no (analytical)instrument devised by man that will directly measure toxicity! Knowing chemical concentrations is essential, but these measurements, however precise, are not of themselves adequate predictors of toxicity." It is unlikely that any one biological technique or organism will serve as the universal indicator and morphological deformities in chironomid larvae are not offered here as a panacea either, but they can provide a powerful supplementary or complementary tool for dealing with contaminants in freshwater ecosystems.

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15) Comparison of community responses based on deformities in the ligulae and antennae of their Procladius spp. populations.

Table 1. Co-ordinates and possible contaminant status of sites sampled for Procladius larvae. Legend: O-organics, M-metals, S-sewage, R-radionuclides.

Site	Longitude N	Latitude W	Status
St. Lawrence River			
Lac St-Louis Site 1	45 24'23"	73 34'23"	O,M
Lac St-Louis Site 2	45 19'54"	73 55'43"	O,M
Lac St-Louis Site 3	45 19'12"	73 53'35"	O,M
Lac St-Louis Site 4	45 19'07"	73 53'33"	O,M
Lac St-Louis Site 5	45 19'10"	73 53'41"	O,M
Lac St-Louis Site 6	45 19'08"	73 53'23"	O,M
Lac St-Louis Site 7	45 19'15"	73 52'08"	O,M
Lac St-Louis Site 8	45 20'50"	73 48'41"	O,M
Lac St-Louis Site 9	45 25'43"	73 40'26"	O,M
Laprairie basin Site 3	45 27'40"	73 30'04"	O,M,S
Laprairie basin Site 7a	45 24'47"	73 30'02"	O,M,S
Laprairie basin Site 13a	45 24'28"	73 31'31"	O,M,S
Southern Indian Lake-Notigi Reservoir			
Wupaw Bay basin	56 45'19"	99 07'12"	M (Hg)
South Bay basin	56 43'55"	99 05'02"	M (Hg)
Mynarski Lake basin	56 07'32"	99 12'00"	M (Hg)
Rat Lake basin	56 05'31"	99 45'43"	M (Hg)
Last Mountain Lake Site I	50 47'23"	104 56'13"	S,O,M?
Last Mountain Lake Site II	50 59'42"	105 11'58"	O?
Tobin Lake Site 2	53 28'44"	103 50'51"	O,M
Tobin Lake Site 17	53 33'16"	103 28'16"	O,M
Tobin Lake Site V	53 37'54"	103 36'06"	O,M
Tobin Lake Site VI	53 37'42"	103 31'06"	O,M
Port Hope Harbour	43 56'36"	78 12'12"	O,M,S,R

Table 2. Basic classification categories and values for indexing individual types of deformities in the ligula of *Procladius* spp. larvae.

Step	Feature		Basic Index Number
1	Basic classification category	5 teeth	1
		4 or 6 teeth	2
		3 or 7 teeth	4
		2 or 8 teeth	8
		1 or 9 teeth	16
		0 or 10 teeth	32
		>10 teeth	–
2	Outer teeth	each	2
3	Overlapping teeth	each	4
4	Accessory teeth	each	8
5	Forked teeth	each	16
6	Fused ligula/paraligula	each	32
7	Massive/asymmetrical		64

Table 3. Examples of estimating the Index of Morphological Response (IMR) for ligulae of *Procladius* specimens from text Figures 1 and 2.

Fig. No.	Number of Teeth											Modifications of Outer Teeth		Over-Lapping Teeth			Accessory Teeth			Forked Teeth			Fusing of Ligula and Paraligula		Massive or Asymmetrical Teeth		Other	Index of Morphological Response (IMR)
	0	1	2	3	4	5	6	7	8	9	>9	left	right	1	2	>2	1	2	>2	1	2	>2	left	right	Mass.	Asym.		
1a																												0
b						1																						1
c					2																							2
d							2																					2
e								4																				4
f					2								2															4
g					2							2		4														8
h						1											8											9
i						1														16								17
j						1														16								17
k					2															16								18
l						1						2								16								19
m				4																16								20
n						1											8			16								25
o					2												8			16								26
p						1											8	8		16								33
2a						1																		32				33
b						1																	32					33
c					2																		32					34
d					2							2											32					36
e					2																32							34
f						1												16					32					49
g					2															16				32				50
h					2									4			8			16				32				62
i						1																	32	32				65
j						1																				64		65
k						1																				64		65
l				4														16			48							68
m		8										2		4											64			78
n										16															64			80
o					2									4										32	64			102
p	32																						32	32	64			160

Table 4. Basic classification categories and values for identifying individual types of deformities in the antennae of Procladius larvae.

Step	Feature	IMR Values
1	Basic Classification categories	
	a) loss of genuine segments	5, 9, 13, 17, and 21
	b) presence of questionable segments	7, 11, 15, and 19
2	Reduction in antennal length	1 - 9
3	Displacement, loss or addition of ring organs	1 - 2
4	Apical fusing of basal segments	2
5	Displacement, loss or addition of sensory organs	2
6	Structures of unknown homology	
	a) major structures	2
	b) minor structures	1

Table 5. Examples of estimating the Index of Morphological Response (IMR) for antennae of Procladius specimens from text Figure 3.

Identification	Basic Index Number	Length Reduction Factor	Ring Organ	Apical Fusing	Sensory Organs	Structures of Unknown Homology Major	Structures of Unknown Homology Minor	Other	Index of Morphological Response
3d	17	1	7	–	2	–	1	–	30
e	15	1	–	–	2	8	–	–	26
f	15	–	–	–	–	–	2	–	17
g	5	–	–	–	2	–	–	–	7
h	5	–	–	–	2	–	–	–	7

Table 6. Frequency (%) of deformities in Procladius liqulae in pre-settlement, post-settlement, and contemporary communities in the Bay of Quinte, Lake Ontario. Adapted from Warwick (1980).

Fauna	Depth of Sediment (cm)	Age (yr)	Type of Deformity	$ISLD_{Procladius}$	$ISLD_{Total}$
Contemporary	0	1972	Mod. outer	1.61	0.498
Subfossil	4.5	1951	6-teeth	3.57	0.354
	9.5	1928	4-teeth	7.14	0.467
	14.5	1907	4-teeth	3.33	0.272
	39.5	1849	4-teeth	2.78	0.224
	89.5	1087	Mod. outer	0.42	0.090
	139.5	238 B.C.	Mod outer	0.45	0.088

TABLE 7. Comparison of the frequency (%), severity (ISLD) and community response of ligulae deformation in *Procladius* spp. larvae from the Lac St-Louis and Laprairie basins of the St. Lawrence River.

	Lac St-Louis									Laprairie Basin	
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 3	Site 7a
Number of larvae examined	46	253	71	368	492	441	369	704	47	62	17
Number of *Procladius* larvae	19	190	52	281	391	324	142	234	30	11	4
Number of deformed ligulae	1	12	2	15	24	18	6	14	2	3	1
Frequency of deformed ligulae	5.26	6.32	3.85	5.34	6.14	5.56	4.23	5.98	6.67	27.27	25.00
Number of evaluated ligulae	1	12	2	15	24	18	6	14	2	3	1
Total IMR	33	214	80	435	267	215	69	121	52	105	19
Average IMR	33.00	17.83	40.00	29.00	11.13	11.94	11.50	8.64	26.00	35.00	19.00
$ISLD_{Procladius}$	1.74	1.13	1.54	1.55	0.68	0.66	0.49	0.52	1.73	9.55	4.75
$ISLD_{Total}$	0.717	0.846	1.127	1.182	0.543	0.488	0.187	0.172	1.106	1.694	1.118

TABLE 8. Comparison of the frequency (%), severity (ISLD) and community response of ligulae deformation in *Procladius* spp. larvae from the Mynarski Lake and Rat Lake basins of Southern Indian Lake – Notigi Reservoir, Tobin Lake and Port Hope Harbour.

Sample designation	Mynarski Lake (summer)	Rat Lake (summer)	Last Mountain Lake Site 1	Tobin Lake Site 2	Tobin Lake Site 17	Port Hope Harbour (B,C,E)
Number of larvae examined	734	1260	1174	1010	309	77
Number of *Procladius* larvae	76	11	619	344	97	57
Number of deformed ligulae	5	1	6	9	1	7
Frequency of deformed ligulae	6.58	9.09	0.97	2.62	1.03	12.28
Number of evaluated ligulae	5	1	6	9	1	7
Total DMR	75	33	124	294	33	170
Average DMR	15.00	33.00	20.67	32.67	33.00	24.29
$ISLD_{Procladius}$	0.99	3.00	0.20	0.85	0.34	2.98
$ISLD_{Total}$	0.102	0.026	0.106	0.291	0.107	2.208

TABLE 9. Comparison of the frequency (%), severity (ISLD) and community response of antennal deformation in Procladius larvae from the Lac St-Louis basin of the St. Lawrence River, Tobin Lake, Last Mountain Lake and Port Hope Harbour.

	Lac St-Louis						Tobin Lake	Last Mountain Lake		Mynarski Lake
	Site 2	Site 4	Site 5	Site 6	Site 7	Site 8	Site 2	Site I	Site II	
Number of larvae examined	253	368	492	441	369	704	1010	1174	935	734
Number of Procladius larvae	190	281	391	324	142	234	344	619	93	76
Number of deformed antennae	2	6	7	4	1	5	3	2	1	1
Frequency of deformed antennae(%)	1.05	2.14	1.79	1.23	0.70	2.14	0.87	0.32	1.08	1.32
Number of evaluated antennae (d)	2	6	7	4	1	5	3	2	1	1
Total IMR	32	65	51	34	11	64	36	14	7	9
Average IMR	16.00	10.83	7.29	8.50	11.00	12.80	12.00	7.00	7.00	9.00
$ISAD_{Procladius}$	0.17	0.23	0.13	0.10	0.08	0.27	0.10	0.02	0.08	0.12
$ISAD_{Total}$	0.127	0.177	0.104	0.077	0.030	0.091	0.036	0.012	0.008	0.012

Table 10. Trace metal concentrations in Lac St-Louis (1985) and Laprairie (1976) basin. From Champoux and Sloterdijk (1988) and Serodes (1978). In $\mu g.g^{-1}$. Values exceeding MDE criteria underlined.

	Lac St-Louis Sites (Champoux And Sloterdijk 1988)				Laprairie Basin Sites (Serodes 1978)			MDE
	nr. Site 2 (L-12)	ca. Sites 3-6 (L-21)	Site 7 (L-2)	Site 8 (L-6)	Site 3	Site 7	Site 13	Criteria
Lead	65	101	40	27	100	45	38	50
Mercury	0.45	2.25	1.38	2.20	0.09	0.75	2.77	0.30
Chromium	-	-	92	60	53.0	75.5	80.5	25
Zinc	370	686	155	142	127	300	342	100
Nickel	55	50	45	32	32.8	49.6	48.4	25
Copper	68	64	46	40	30.9	55.9	53.5	25
Beryllium	-	-	-	-	1.46	1.67	1.52	-
Cobalt	-	-	16	3	-	-	-	50
Vanadium	-	-	104	53	-	-	-	-
Arsenic	6.39	12.90	5.66	5.33	-	-	-	8
Cadmium	1.70	14.00	1.40	1.00	-	-	-	0.10
Selenium	1.23	1.10	0.77	1.14	-	-	-	-
K	7	7	9	9	6	6	6	
Index of Contamination (Ic)	1.99	5.22	1.81	1.98	1.37	2.27	3.42	

Note: - = no data

Table 11. Organic contaminant concentrations for comparable sites in Lac St-Louis, 1985. From Champoux and Sloterdijk (1988). In $\mu g.g^{-1}$

	Lac St-Louis Sites			
	nr. Site 2 (L-12)	ca. Sites 3-6 (L-21)	Site 7 (L-2)	Site 8 (L-6)
Hexachlorobenzene	<0.004	0.015	0.008	<0.004
Anthracene	0.040	-	0.020	0.001
Fluoranthene	0.030	-	<0.001	0.010
Pyrene	<0.001	-	0.250	0.020
Chrysene	0.080	-	<0.001	0.040
Naphtalene	0.050	-	0.040	<0.010
Acenaphthylene	<0.020	-	0.220	<0.020
Phenanthrene	0.020	-	0.110	<0.001
Benzo(a)anthracene	0.007	-	0.550	0.009
Benzo(b)fluoranthene	0.070	-	0.280	0.030
Benzo(k)fluoranthene	0.010	-	0.080	0.010
Benzo(a)pyrene	0.030	-	0.240	0.020
Dibenzo(ah)anthracene	0.020	-	0.800	0.090
Benzo(ghi)perylene	0.040	-	0.650	0.040
Indeno(123cd)pyrene	0.050	-	0.480	0.050
Total PCB	<0.090	0.110	<0.090	<0.090
Total PAH	0.447	-	3.720	0.320
Index of Contamination (I_c)	3.65	20.33	2.90	2.50

Note: - = no data

Table 12. Trace metal concentrations for sites in Southern Indian Lake – Notigi Reservoir, Tobin Lake and Port Hope Harbour, Lake Ontario. In $\mu g.g^{-1}$

	Southern Indian Lake – Notigi Reservoir							
	Rat Lake		Mynarski Lake	South Bay	Wupaw Bay	Tobin Lake		Port Hope Harbour
	(spring)	(summer)	(summer)	(summer)	(summer)	Site 2	Site 17	
Lead	–	–	–	–	–	15	25	483
Mercury	0.104	0.113	0.250	0.055	0.108	0.084	0.046	–
Chromium	–	–	–	–	–	89	84	50
Zinc	100.0	70.8	66.0	72.5	59.6	77	91	205.7
Nickel	–	–	–	–	–	11	36	58
Copper	11.6	19.4	43.6	22.3	11.8	12	30	122
Beryllium	–	–	–	–	–	–	–	–
Cobalt	14.6	46.5	18.0	45.8	27.4	11	9.5	57
Vanadium	–	–	–	–	–	–	–	33
Arsenic	–	–	–	–	–	7.7	6.9	–
Cadmium	0.1	1.9	2.5	1.2	1.5	0.2	0.4	1.2
Selenium	–	–	–	–	–	–	0.5	0.7
K	5	5	5	5	5	9	9	7
Index of Contamination(I_c)	0.44	0.94	1.22	0.78	0.70	0.80	1.00	3.32

Note: – = no data

TABLE 13. Levels of radionuclides in surficial sediments of the basin and west slip of Port Hope Harbour. From Hart et. al. (1986).

Parameter	Units	Mean Concentration (n=13)	Concentration Range
U	$\mu g.g^{-1}$	92.5	3.5–1280
Th-230	$Bq.g^{-1}$	6.78	0.063–76.6
Ra-226	$Bq.g^{-1}$	1.56	0.031–297
Pb-210	$Bq.g^{-1}$	6.54	0.60–682
Po-210	$Bq.g^{-1}$	5.79	0.30–739
Th-232	$Bq.g^{-1}$	0.20	0.015–5.2
Th-228	$Bq.g^{-1}$	0.10	0.014–2.2

Table 14. Interbasin comparisons of Indices of Contamination (I_c) based on overlapping combinations of trace metals. Underlined values indicate indices based on total number of metals analysed. Accompanying values not underlined indicate indices based on that subset of metals.

	Lac St-Louis				Laprairie Basin			Southern Indina Lake – Notigi Reservoir					Tobin Lake		Port Hope
Trace Metal Combinations	nr. Site 2 (L-12)	ca. Sites 3-6 (L-21)	Site 7 (L-2)	Site 8 (L-6)	Site 3	Site 7	Site 13	Rat Lake (spring)	Rat Lake (summer)	Mynarski Lake (summer)	South Bay (summer)	Wupaw Bay (summer)	Site 2	Site 17	Harbour (inner)
Zn, Cu, Pb, Ni, Hg As, Cd, Co, Cr			1.86	1.81									0.80	1.00	
Zn, Cu, Pb, Ni, Hg As, Cd	1.99	5.22	1.81	1.98									0.49	0.79	
Zn, Cu, Pb, Ni, Hg Cr			2.38	2.43	1.37	2.27	3.42						0.97	1.26	
Zn, Cu, Pb, Ni, Hg	2.28	4.19	2.12	2.43	1.22	2.12	3.50						0.45	0.84	
Zn, Cu, Pb, Ni	2.48	3.36	1.50	1.21	1.45	2.03	2.06						0.50	1.01	4.73
Zn, Cu, Pb, Ni, Cr			1.93	1.45	1.59	2.23	2.30						1.11	1.48	4.18
Zn, Cu, Pb, Ni, Cd Co, Cr			1.63	1.19									0.85	1.14	3.32
Zn, Cu, Hg, Cd, Co			1.94	2.28				0.44	0.94	1.22	0.78	0.70	0.39	0.57	
Zn, Cu	3.21	4.71	1.70	1.51	1.25	2.02	2.78	0.73	0.74	1.20	0.81	0.53	0.63	1.06	3.47

TABLE 15. Comparison of community responses based on deformities in the ligulae and antennae of their *Procladius* spp. populations.

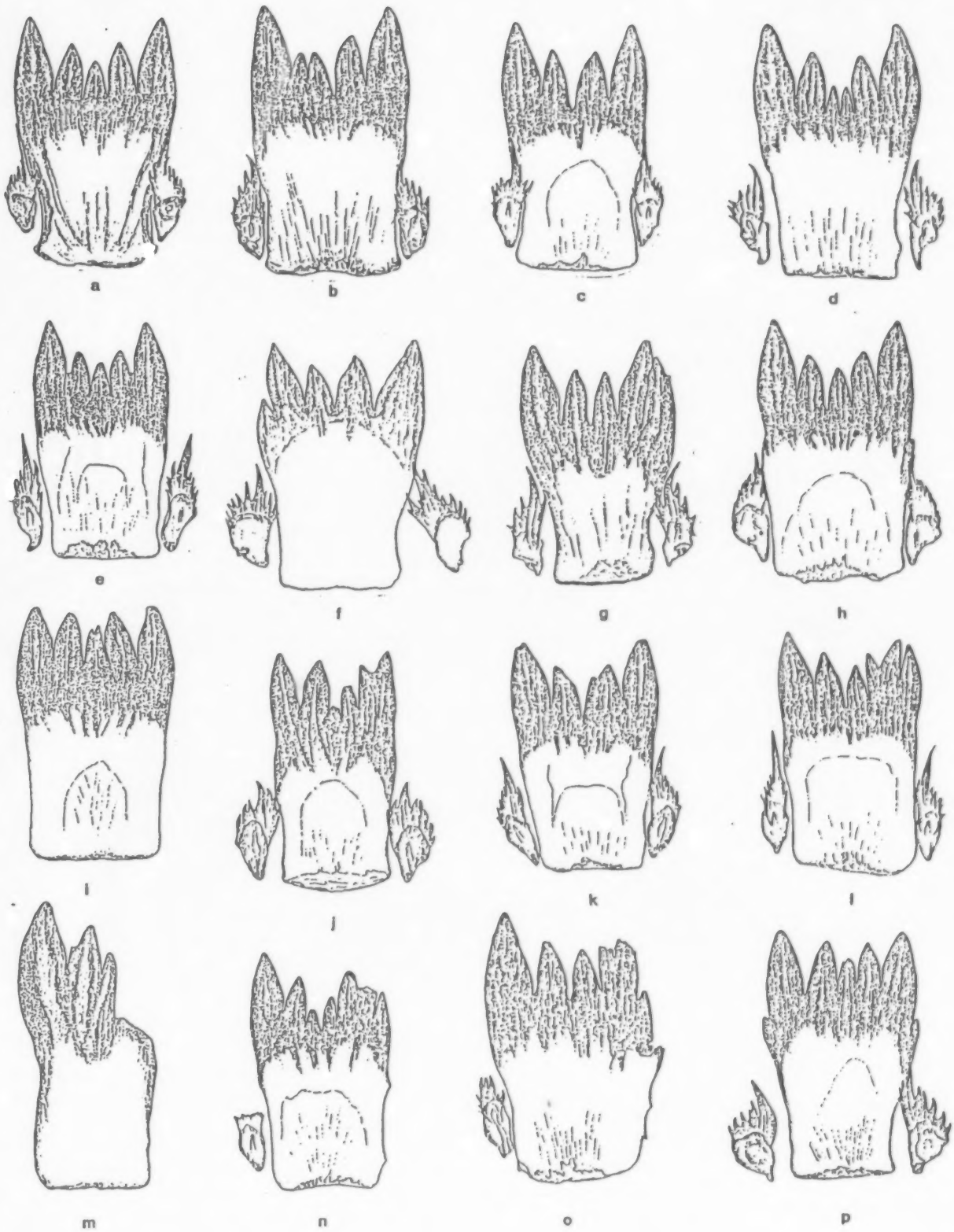
	Procladius Population				Index of Contamination	
	$ISLD_{Total}$	$ISAD_{Total}$	Other	Community Response (subtotal)	Trace Metals	Organics
St. Lawrence River						
Lac St-Louis Site 1	0.717	0	-	0.717	-	-
Lac St-Louis Site 2	0.846	0.127	-	0.973	1.99	3.65
Lac St-Louis Site 3	1.127	0	-	1.127	-	-
Lac St-Louis Site 4	1.182	0.177	-	1.359	5.22	20.33
Lac St-Louis Site 5	0.543	0.104	-	0.647	-	-
Lac St-Louis Site 6	0.488	0.077	-	0.565	-	-
Lac St-Louis Site 7	0.187	0.030	-	0.217	1.81	2.90
Lac St-Louis Site 8	0.172	0.091	-	0.263	1.98	2.50
Lac St-Louis Site 9	1.106	0	-	1.106	-	-
Laprairie Basin Site 3	1.694	0	-	1.694	1.37	-
Laprairie Basin Site 7a	1.118	0	-	1.118	2.27	-
Laprairie Basin Site 13a	0	0	-	0	3.42	-
Southern Indian Lake -Notigi Reservoir						
Wupaw Bay Basin	0	0	-	0	0.70	-
South Bay Basin	0	0	-	0	0.78	-
Mynarski Lake Basin	0.102	0.012	-	0.114	1.22	-
Rat Lake Basin (spring)	0	0	-	0	0.44	-
Rat Lake Basin (summer)	0.026	0	-	0.026	0.94	-
Last Mountain Lake Site I	0.106	0.012	-	0.118	-	-
Last Mountain Lake Site II	0	0.008	-	0.008	-	-
Tobin Lake Site 2	0.291	0.036	-	0.327	0.80	-
Tobin Lake Site 17	0.107	0	-	0.107	1.00	-
Tobin Lake Site V	0	0	-	0	-	-
Tobin Lake Site VI	0	0	-	0	-	-
Port Hope Harbour(Sites B,C,E)	2.208	0	-	2.208	3.32	-

LIST OF FIGURES

1) Deformities in ligulae of Procladius larvae: a) normal and b-p) deformed ligulae.

2) Deformities in ligulae of Procladius larvae: a-p) deformed ligulae.

3) Deformities in antennae of Procladius larvae: a) normal (with apical segments enlarged b,c) and d-h) deformed antennae.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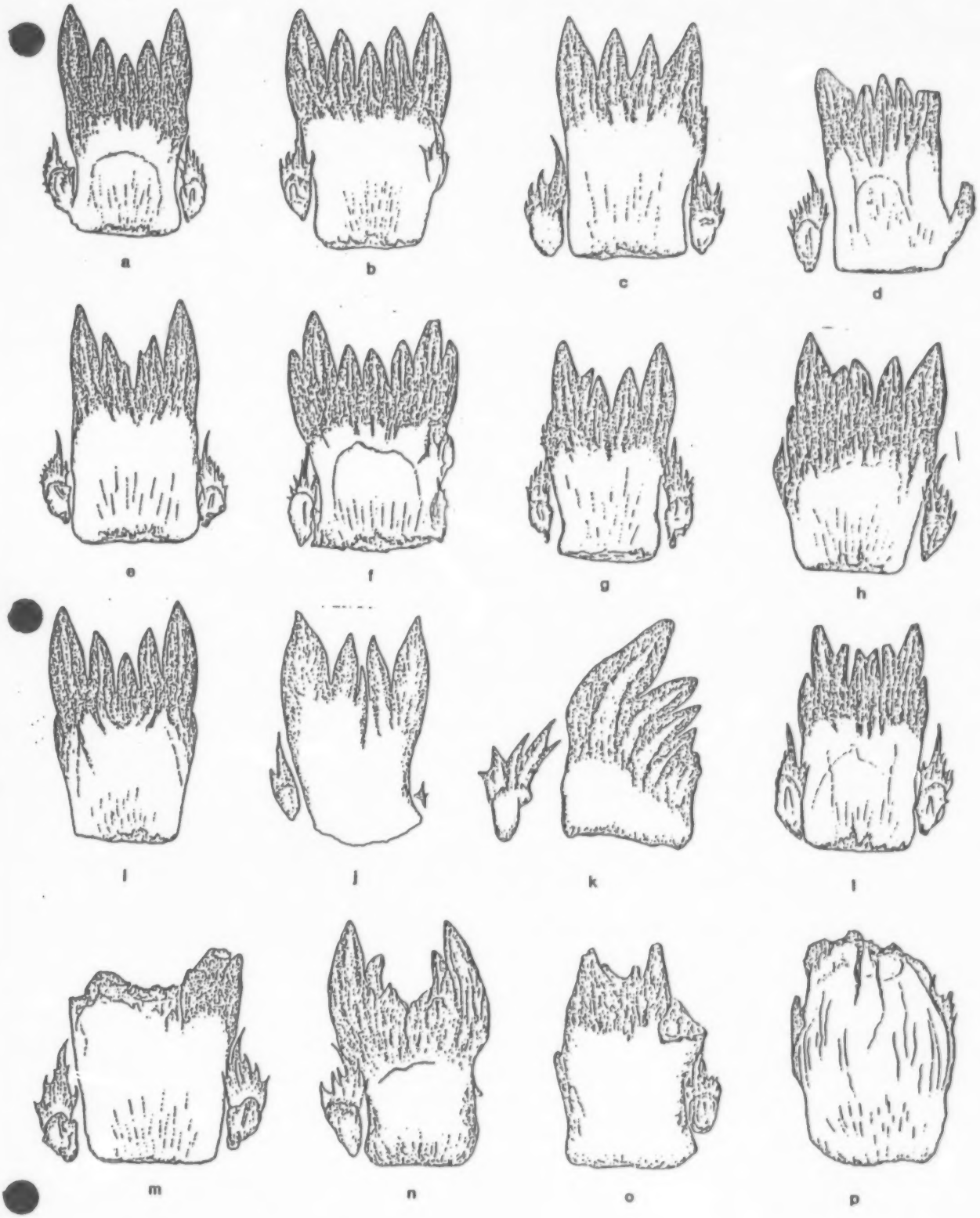
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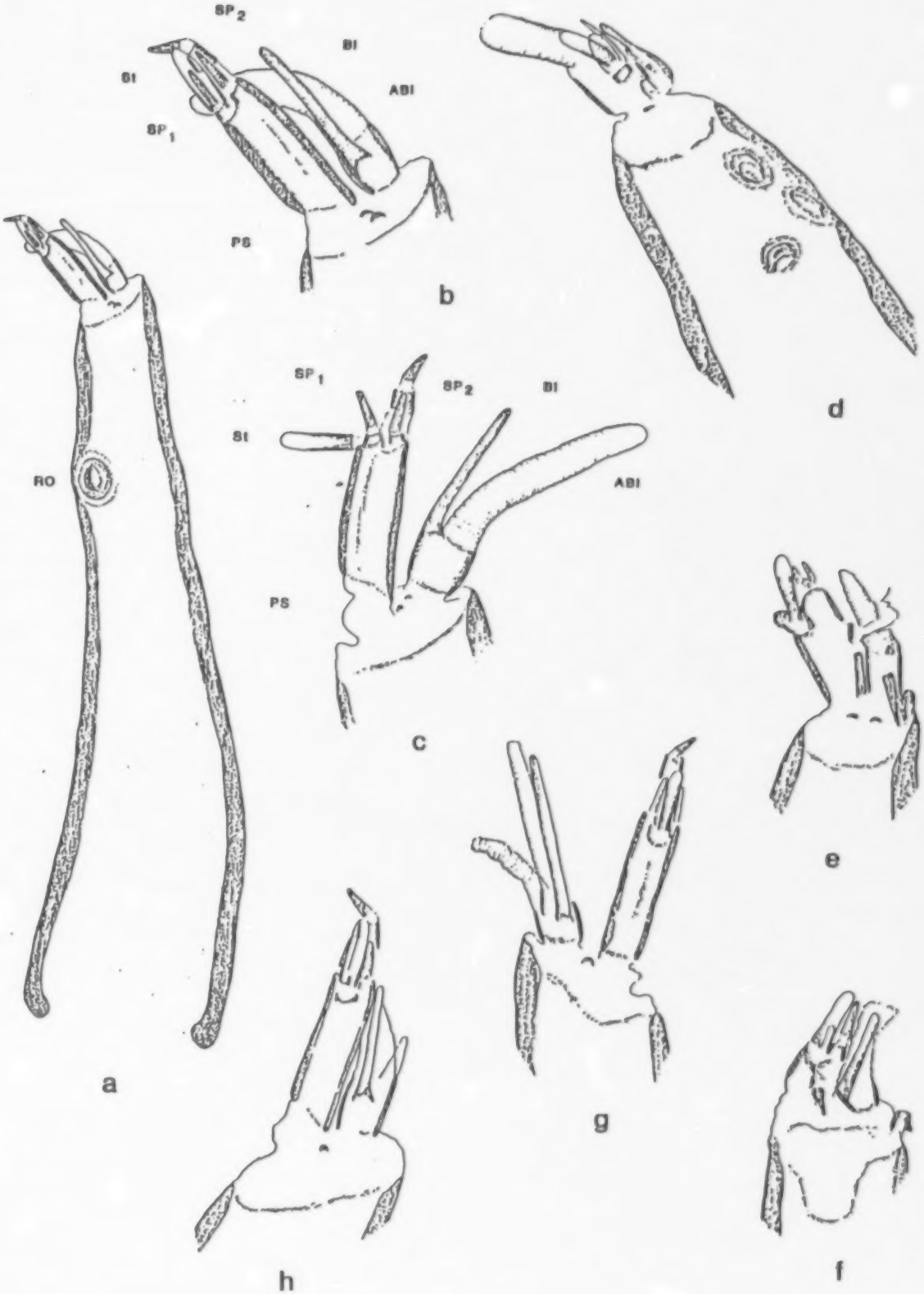
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